Geo-Magnetic Disturbance Analysis of HV and EHV Grids

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Geomagnetic Storm and Electric Power System

- Solar Flare
- Induced DC Voltage
- Monitoring (NOAA)
- Half-Cycle Saturation
- GIC flow

Effects on Power System
- Increased VAR losses
- Increased Harmonics
- Increased Hotspot Temp.

Source: Siemens PTI
Geomagnetic Storms

- **Solar Cycle**: maximum in solar activity that takes place approximately every eleven years
  
  - Large geomagnetic storms can occur with smaller cycles.
  
  - The largest geomagnetic storms on record occurred during smaller-than-average cycles.

- Electric utilities need to plan not only for Solar Cycles, but any GMD event that can occur.

- Electric utilities will have **hours to 2-day advance notice** of geomagnetic storm. [NOAA Space Weather Prediction Center (SWPC)]
Overview of GMD Research Activities

Refinement and Enhancement

Scenario Definition

Modeling

Forecasting

Vulnerability Assessment

Mitigation

Risk Management

Industry Awareness

Measurement

Outputs

Photo Sources: NOAA Space Weather Prediction Center; SOHO (ESA & NASA)

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Creating Scenario Definition

Rough visual extrapolation gives 1/100 year 10-second amplitude of 20 V/km

Source: Statistical Occurrence of Modeled Geoelectric Field in Quebec (Pulkkinen et al., 2008)
Effect of Latitude and Geology on Electric Field Gradient

Geo-Magnetic (350km Apex) Boundaries of Interest

Geomagnetic Latitude Contours

Geo-Magnetic Latitude Contours

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Geology

Bedrock Geology

EXPLANATION

- Cretaceous sedimentary rocks
- Jurassic sedimentary rocks
- Pennsylvanian sedimentary rocks
- Mississippian sedimentary rocks
- Devonian sedimentary rocks
- Silurian sedimentary rocks
- Ordovician sedimentary rocks
- Cambrian sedimentary rocks
- Precambrian-Josephine Sandstone
- Precambrian-Hinchley Sandstone
- Precambrian rocks, undifferentiated

Contact

A-A' Line of hydrogeologic section

SCALE: 1" equals 100 MILES

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GIC Induced from GMD Activity

GIC Conduction Paths
Drivers of GIC Flow

(PowerWorld Display)
Modeling of GIC Flows

- Scenario Definition
- Earth Conductivity
- Calculate Earth Surface Electric Field
- Power System Topology With DC Resistance
- Run OpenDSS Software
- GIC Flows
System Planning Studies for Vulnerability Assessment

GIC Currents from OpenDSS

Develop Transformer Models

Power System Topology with AC Impedance

System Planning Studies (e.g., PowerWorld or PSS®E)

Transformer Vulnerability

Power System Vulnerability
Sunburst Network GIC Measurement: Halloween Storms of 2003

Neutral DC (A)

October 29, 2003

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Developing and Validating Transformer Models

Develop detailed model of one or two transformer types
Ex: 3-phase, 3-limb, core type, Model ABC
Ex: 3-phase, 7-limb, core type, Model XYZ

Electrical Thermal
Electrical Thermal

Test actual transformers to validate modeling methodology
(Measure harmonics, VARS, temperature, etc.)
3-phase, 3-limb, core type, Model ABC
3-phase, 7-limb, core type, model XYZ

OpenDSS (GIC): Predicted GIC
Sunburst Measurement Network: Actual GIC

For each transformer type, model a handful of different transformers of that type
(e.g., variations in number of turns, cooling systems, etc.)
3-phase, 3-limb, core type, Model ABC
3-phase, 7-limb, core type, Model XYZ
3-phase, 5-limb, core type, Model JKL
3-phase, 3-limb, core type, Model AAB

Model DEF
Model MNO
Model PQR
Model VWX
Model GHI
Model MNO
Model PQR
Model VWX

Filter these models – Select the most conservative result for each type for system modeling and transformer vulnerability analysis

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Transformer Half-Cycle Saturation from GIC

Harmonics Heating Increased Vars

NERC GMD Workshop April 2011
Abstract—Geomagnetically induced currents (GICs) in power systems can attribute to problems ranging from transformer overheating, misoperation of protective relays, and voltage instability. Assessment of the geomagnetic hazard to power systems requires accurate modeling of the GICs that are expected to occur. However, to date, there are no publicly available test cases to validate software programs used to compute GIC. The following paper presents a hypothetical network that can be used as a test case for validating results from GIC modeling software. The network contains many features found in real networks such as different voltage levels, two and test cases to validate software [8], no IEEE test case exists to validate GIC modeling software. To facilitate the testing and comparison of GIC modeling procedures, a benchmark test case is presented. The details of the test case are designed to: 1) include many features found in typical high voltage (HV) and extra high voltage (EHV) networks, and 2) show the results obtained with four independent software programs. To aid those involved in the software validation process, the values obtained at key points in the calculation process are also presented.
GIC Test Case – One Line Diagram

Purpose: Provide a benchmark for software tools that compute GICs in HV/EHV networks
GIC Test Case – Hypothetical Geography

500 kV

345kV
Compensating for Earth Curvature

\[ V = E_N L_N + E_E L_E \]

\[ L_N = (111.133 - 0.56 \cos(2\phi)) \cdot \Delta \text{lat} \]

\[ L_E = (111.5065 - 0.1872 \cos 2\phi) \cdot \cos \phi \cdot \Delta \text{long} \]
Special Models for GIC Calculation - Transformers

2-winding Delta-Wye

3-winding Wye-Delta-Wye

Autotransformer w/ Delta Tertiary
Special Models for GIC Calculations - Lines

GMD source appears in series with line resistance

\[ V = E_N L_N + E_E L_E \]

OpenDSS Simulations are performed at 0.1 Hz
OpenDSS Script

- GIC Test Case is provided with the standard installation
  - [www.Sourceforge.net](http://www.Sourceforge.net)
  - Search for OpenDSS
- Described in the User Manual (snippet of script):

```plaintext
!GIC Line Data
New GICLine.1-Bus2-Bus3 bus1=2 bus2=3 R=3.512 Lat1=33.613499 Lon1=-87.373673 Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=0.00
New GICLine.2-Bus2-Bus17 bus1=2 bus2=17 R=3.525 Lat1=33.613499 Lon1=-87.373673 Lat2=34.310437 Lon2=-86.365765 EE=1.00 EN=0.00
New GICLine.3-Bus15-Bus4 bus1=15 bus2=4 R=1.986 Lat1=33.955058 Lon1=-84.679354 Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=0.00
New GICLine.4-Bus17-Bus16 bus1=17 bus2=16 R=4.665 Lat1=34.310437 Lon1=-86.365765 Lat2=33.955058 Lon2=-84.679354 EE=1.00 EN=0.00
New GICLine.5-Bus4-Bus5 bus1=4 bus2=5 R=2.345 Lat1=33.547885 Lon1=-86.074605 Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00
New GICLine.6-Bus4-Bus5 bus1=4 bus2=5 R=2.345 Lat1=33.547885 Lon1=-86.074605 Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00
```
Mitigating GMD Effects

Model Best Practices: “What-if?” Analyses Using OpenDSS (GIC) and Power Flow Models

Timeframes:
1. In Advance
2. Warning (a few days)
3. Alert (hours)

Integrate Into Risk Management Strategy

Assess Effectiveness in Actual GMDs

Refine and Prioritize

Define Optimal Operating Strategies (1, 2, 3)

Define and Assess Hardware Retrofits (1)

Define Equipment Procurement Standards (1)

Spares Strategies (STEP, RecX, SEDTF) (1)

Refine and Prioritize

Assess Effectiveness in Actual GMDs

Integrate Into Risk Management Strategy

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Neutral Blocking Capacitors

Hydro-Quebec Transenergie Interconnection
Questions?
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